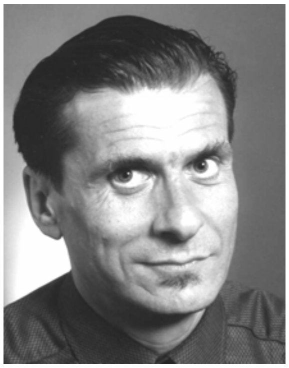
Specsmanship: the artistry of sugarcoating performance specifications

by Michael E. Becker



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Specsmanship: "the often inappropriate use of specifications or measurement results to establish putative superiority of one entity over another, generally when no such superiority exists" [Wikipedia], is covering the full range from putting out hyped sensational rumors, spreading urban legends and hysterics to fair data swindle [1].

It usually starts quite innocently: you want to or you have to procure a new desktop computer monitor for your home office or a new television set. In order to get the best performance for the money you will be asked to pay you are trying to spot the performance specifications that are relevant for your intended application as a basis for comparison of different products [2].

When you have a look at the available data you are invited to choose between contrast values of e.g. 500 and 1,000,000 and you may start to wonder how relevant these numbers are for your actual application. At the other end of the scale you are lured by vanishing response times in the range of a few milliseconds, suggesting that shorter response times naturally warrant better display of moving images.

Instead of being confronted with numerous unexplained terms and skyrocketing or vanishing numbers, users of electronic display devices may want to have a reliable (i.e. unbiased), understandable, and reasonable basis of data describing the performance of the product according to its intended application as a solid basis for a purchasing decision [1]. At the same time, however, customers must realize that electronic visual displays have become so sophisticated and complex that their performance just cannot be characterized and rated by a single "figure of merit". Depending on the intended application (e.g. office work, display of video and movies, graphics and design, computer games, home cinema, nomadic ICT devices, etc.) emphasis must be placed on different individual aspects of performance, at least as long as the ideal display device is not available at affordable prices.

This is the first in a series of articles in which we shall present latest specsmanship achievements and in which we shall try to explain which aspects of the performance specifications are of importance for your intended application of a display screen.

Contrast: dreams vs. facts

Contrast values of 1 million? The contrast of display screens based on emission of light (e.g. CRTs and PDPs) are often specified with extremely high values. The contrast of e.g. Sony's "XEL-1" OLED TV-set is specified with a value of 1,000,000 (one million, see e.g. http://www.sonystyle.com).

- Under which conditions can such contrast values be measured?
- How relevant are these contrast values for the actual performance of TV-screens?

These are the questions we try to *illuminate* in this article.

What is the definition of contrast? *Contrast* in visual perception is the difference in appearance of two or more parts of a field seen simultaneously or successively. The visual *contrast* of a display-screen is defined as the (dimensionless) ratio of the *luminance* of a brighter optical state, L_H, and the *luminance* of a darker optical state, L_L. The luminance (specified in cd/m^2) is the physical quantity corresponding to the perception of *brightness*. This quotient is often called "contrast ratio" (CR) and specified as *number: 1* to indicate that it is without dimension.

In most cases it is the **maximum contrast** that can be achieved with a display screen that is specified in the data-sheet. This maximum contrast is given by the luminance of the full-white state (R=G=B=100%) and the luminance of the full-black state (R=G=B=0). The minimum luminance of display screens based on light-emitting technologies (e.g. CRT and PDP) is very low (theoretically zero) and thus the quotient yielding the contrast becomes quite high (theoretically infinite). In real life, the OFF-luminance of PDPs is in the range of 10^{-2} cd/m^2 since the discharge is never completely off and the OFF-luminance of CRTs is in the same range due to afterglow of the phosphors.

In the case of LCDs light is generated by the backlight unit and the LCD-panel in front of the backlight acts as a spatial modulator for the light via electrically controllable transmission. The range of transmission of LCD-cells with color filters is limited by the technology and in the range from 5% to 0.005%. If the luminance of the brightest state is intended to be 200 cd/m^2 the backlight luminance has to be a factor of 1/0.05=20 higher which means it must amount to 4000 cd/m^2. The darkest state of the LCD-screen is then at a luminance of 0.2 cd/m^2 and the resulting contrast value is CR=1000. Two problems arise in that context:

- it turns out to be difficult to measure luminance values < 1 cd/m^2 in a reproducible way, and
- it is difficult to keep a room that dark that no ambient light will corrupt the measurement.

How is contrast measured? The luminance of the bright state of a television screen is (depending on the state of adaptation of the eye of the observer) typically in the range of some 100 cd/m^2. If this luminance is set too high the observer may unpleasantly experience that as *glare*. In order to be able to measure a contrast of 1 million in a laboratory it must be assured that no ambient light (from e.g. LEDs on the operating panel of instruments) is corrupting the dark state of the object of measurement at a luminance of 10^{-4} cd/m^2 (10^{+2} / 10^{-4} = 10^{+6}). It turns out that realization of this condition is not easy. Moreover, luminance values below 10^{-3} cd/m^2 can be measured accurately only with special and thus more expensive instruments.

When the above mentioned conditions are fulfilled, the luminance of the display under test is first measured in the full-white state and then in the full-black state. The contrast evaluated from these measurements under the specified conditions is named ***full-screen sequential dark-room contrast***. This contrast is relatively easy to measure but it does not correlate very much with the contrast that is relevant for the visual experience of a human observer. A kind of contrast more relevant for visual perception is the contrast that is contained in the same visual field and seen at the same moment in time (*concurrent* contrast).

Implications for the dark laboratory: In order to avoid corruption of the black-state of the display under test at a luminance of 10^{-4} cd/m^2 during the measurement the walls of the room must be painted with low reflectance paint (~5% reflectance) and/or be far away from the object of measurement.

Sony OLED TV "XEL-1" as an example

Scenario 1: The TV-screen with a diagonal of 11-inch is located in a **completely dark room**. The screen shows a black square (0 cd/m^2) of 50mm x 50mm on a white background (100 cd/m^2). The screen is 3 m away from a wall with a (diffuse) reflectance of 18% (photographic gray-chart). The screen is assumed to have a specular reflectance of 5% (an ordinary window pane has a specular reflectance of typically 2 x 0.04 = 8%).

Which contrast does the black square have with respect to the white background?

- An 11-inch screen with an aspect ratio of 16:9 has a surface area of 244mm x 137mm = 33.428 10^{-3} m^2
- The light emitting surface thus is 33.428 10^{-3} m^2 – (0,05 m)^2 = 30.93 10^{-3} m^2
- The illuminance E of the wall in 3 m distance becomes:

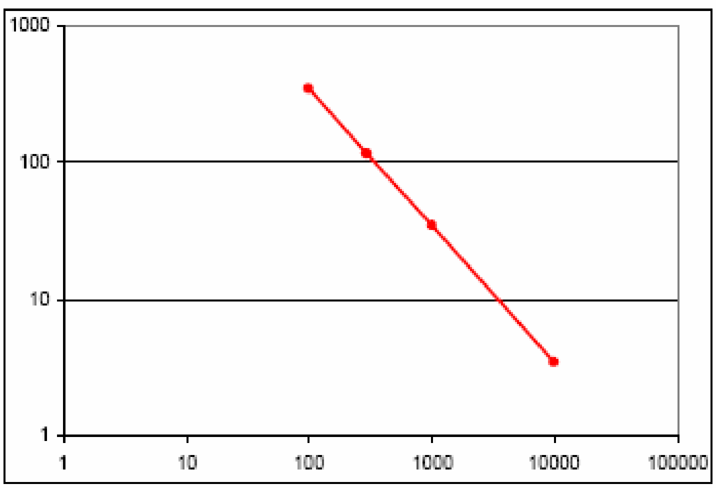
$$E = (L*A) / d^2 = 100\ \text{cd/m}^2 * 30.93\ 10^{-3}\ \text{m}^2 / 9\ \text{m}^2 = 0.34364\ \text{lux}$$

- The luminance L of the wall then becomes:
  $L = E * \rho/\pi = 0.019689\ cd/m^2 \sim 0.02\ cd/m^2$
- The luminance reflected from the screen at the location of the black spot then is:
  $L_R = 0.02 * 0.05 = 1\ 10^{-3}\ cd/m^2$
- The contrast then becomes:
  $C = 100\ cd/m^2 / 1\ 10^{-3}\ cd/m^2 = 10^{+5}$

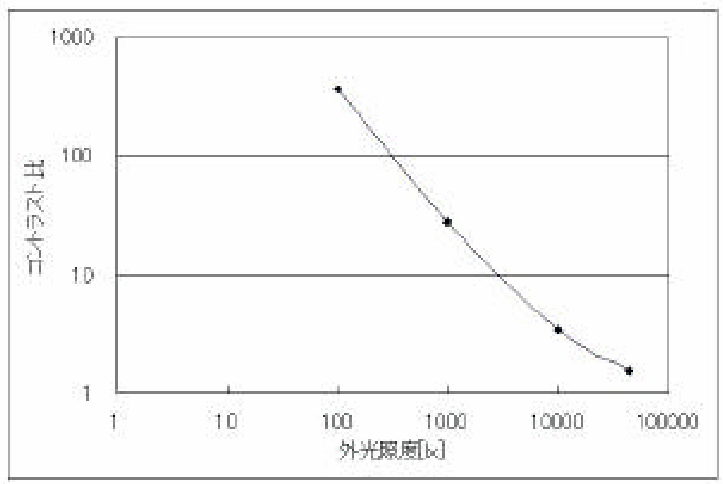
This means that the contrast even under such severe darkroom conditions is reduced from 10^{+6} to 10^{+5} by reflection of the wall illuminated by the bright area of the TV-screen.

Scenario 2: The same TV-screen now is in a dim room at an illuminance of 100 lux (home theater conditions in the living room). This illuminance (we can neglect here the effect from the white TV-screen) causes the wall to have a luminance of 5.7 cd/m^2 (please note that most white wall papers have a reflectance of 70% - 80% instead of the 18% used here!). The luminance of the wall reflected from the black area on the TV-screen then becomes 0.285 cd/m^2 and thus the contrast is 349!

Scenario 3: The same TV screen now is in a room at an illuminance of 300 lux (minimum illuminance for office work). This illuminance (we can again neglect here the effect from the white TV-screen) causes the gray wall to have a luminance of 17.2 cd/m^2 (please note that most wall papers have a reflectance of 70% - 80% instead of the 18% used here!). The luminance reflected from the black spot on the TV screen then becomes 0.86 cd/m^2 and the contrast goes down to 116!



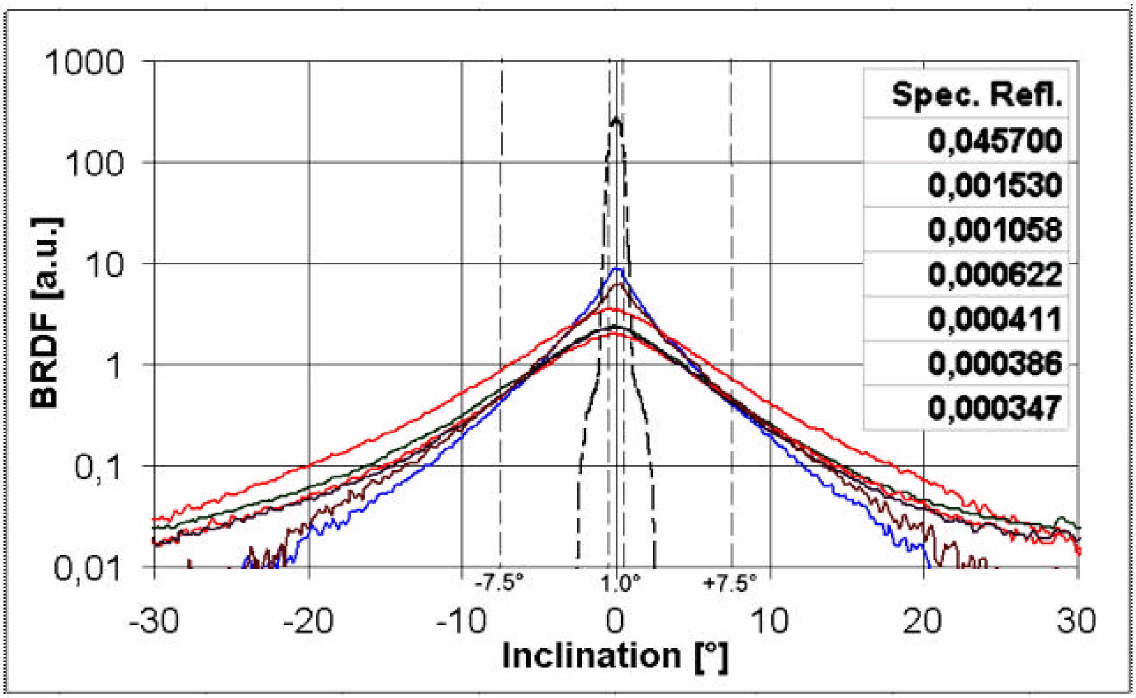
Contrast values versus ambient illuminance (lux) calculated according to the scenarios described above.



Contrast values versus ambient illuminance (lux) according to measurements published at http://techon.nikkeibp.co.jp.

Contrast values used for specification and demonstration of the performance of display devices in data sheets are usually assessed under special conditions and thus often meaningless for actual application situations. In order to assure good visual performance outside of the dark-room where the measurements have been carried out, i.e. under non-vanishing ambient illumination, effective treatment of the surface of the display-screen to reduce reflections is most important [5, 6].

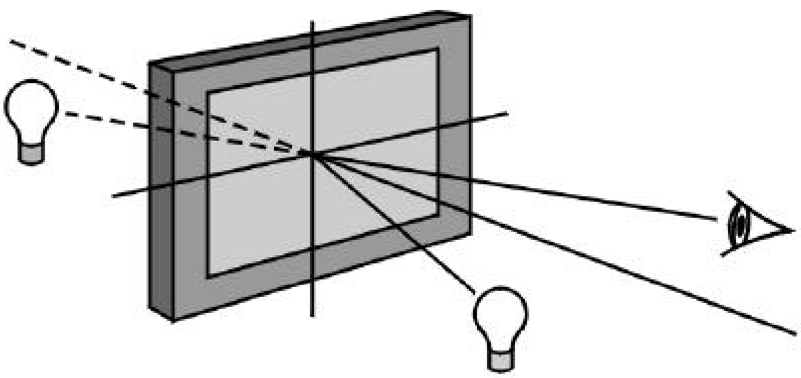
Measures to reduce display reflectance: For many years all LCD-monitors were provided with a matte surface coating that was scattering incident light and thus reducing unwanted reflections of ambient light sources. Recently, the manufacturers marketing divisions spread the news that a smooth LCD surface provides more saturated colors and a higher contrast and soon, shiny surfaces with attractive names became a distinguishing feature among LCD screens. The improvements suggested by these shiny surfaces can indeed be noticed and measured, but only in a completely dark room when no reflecting object is in front of the display (e.g. white shirts are prohibitive). This tiny condition however is not realized in most of the application situations and thus the promised improvements are practically not relevant.

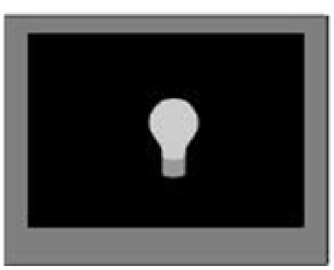


Bidirectional reflectance distribution function (BRDF) of a range of LCD screens showing specular reflectance values in the range of 0.1% - 0.2% for scattering anti-glare coatings (AG), and in the range of 0.06% to 0.03% for combined AG and dielectric anti-reflection coatings [7].

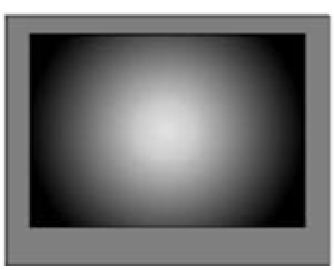
Illustration of the effect of an ambient light source

(Virtual) image of light source in case of specular (mirror like) reflectance.





Specular (mirror like) reflection component only, a distinct image of the light source can be seen.



Haze only, maximum of reflected luminance in specular direction, only a fuzzy blurred image of the source can be seen.

Lambertian diffuse reflectance only as known from white printer/copier paper.

The three basic reflectance components together.

Illustrations from E. F Kelley

Reflections from a display screen can be reduced by anti-glare (AG) layers (rough surface with micro-structures that scatter incident light) and by stacks of smooth dielectric films (anti-reflection coatings). AG layers can be recognized by the fact that no distinct images are visible as reflections in the screen (scattering induces *haze*) and AR coatings can be detected by the purple color of originally white light sources reflected via the screen. The most effective reduction of display reflectance is obtained by AG layers combined with AR coatings [7]. Unfortunately this is also the most expensive approach and thus only applied in special cases (e.g. displays for airplanes).

If you are in a store comparing different display screens, the knowledge of the reflection characteristics illustrated in the figures above helps you to find out which technique is used for reduction of display reflectance. Move your head until a light source in the room is reflected in the screen or bring your own test light source (pocket lamps with the reflector removed and held close to one of your ears are well suited). If you see a distinct image of the light source, there is no scattering AG layer. If the image of the originally white light source has a purple tint, an anti-reflection coating is provided. In the consumer electronics field both measures (AG, AR) are combined only in very rare cases. Make sure that you do not buy a display screen without any treatment for reduction of reflectance or a screen with an additional cover plate without anti-reflection measures. This case becomes obvious by a distinct image of the light source without additional purple tint.

The brighter the surround is in which the display screen is intended to be used (e.g. office workplace close to the window or even in a windowed corner) the lower the display reflections must be in order to provide a good contrast and thus the basis for a good visual performance.

References:

[1] M. E. Becker: "Facing the issue of specsmanship in display standards", Veritas et Visus, Display Standard February 2007
[2] M. E. Becker: "Display usability, performance specifications and standards", Symposium on Display Usability: Modeling, Specification, Measurement & Assessment, NPL Teddington, 7th March, 2006.
[3] http://www.sonystyle.com
[4] http://techon.nikkeibp.co.jp/english/NEWS_EN/20071127/143111/
[5] E. F. Kelley: "Diffuse Reflectance and Ambient Contrast Measurements Using a Sampling Sphere", SID ADEAC06 Digest, pp. 1-5
[6] E. F. Kelley, et al.: "Display Daylight Ambient Contrast Measurement Methods and Daylight Readability", JSID 14, 11, pp. 1019-1030
[7] M. E. Becker: "Display Reflectance: basics, measurement, and rating", JSID 2006, 14, 11, pp. 1003-1017

Further reading:

- Don Williams: "Debunking of Specsmanship: Progress on ISO/TC42 Standards for Digital Capture Imaging Performance", IS&T's 2003 PICS Conference, pp. 77-81
- www.6million-pixel.org see why the number of pixels alone does not sufficiently characterize digital camera performance
- E. F. Kelley : "What Do the Specifications Mean ?", SID04 ADEAC, pp. 15-18